Growth effects of education with the extreme bounds analysis: some evidence from Asia

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Abstract

This paper uses the Extreme Bounds Analysis (EBA) to find robust and permanent growth effects of education by using enrolment ratios and its components in a panel of Asian countries. It is found that male and female primary and secondary enrolment ratios have robust but small permanent growth effects. However, the growth effects of male and female tertiary enrolment ratios are fragile and insignificant. In contrast to the existing estimates in the literature, which do not distinguish between the transitory and permanent growth effects, our estimated permanent growth effects are small but significant.

Keywords: Education and growth, Solow Growth Model, Extreme bounds analysis and Total factor productivity.

JEL: O11, O15

1. Introduction

This paper examines the long run growth effects of education using a panel of fifteen Asian countries over the period 1970-2009. The terms long-run growth rate, permanent growth rate and steady state growth (SSGR) are used synonymously in this paper. The economic benefit of education to improve the SSGR is important as a more educated society translates into higher rates of economic growth. This is evidenced by the large literature that has emerged on education and economic growth; see Mankiw, Romer and Weil (1992), Barro (1991), Hanushek (1995), Temple (2001), Krueger and Lindahl (2001), Gemmel (1996), Benhabib and Spiegel (1992) and Dowrick (1995) among others. The relationship between education and economic growth, with special attention to schooling quality, is examined in Barro (1999), Hanushek and Kimko (2000), Hanushek and Dongwook (1995) and Hanushek and Woessmann(2008) .

Given the current emphasis on education by the United Nations and the Millennium Development Goal (MDG) of achieving education for all by increasing enrolment ratios, this study seeks to investigate empirically, the effect of education, as measured by enrolment ratios, on economic growth. We use primary, secondary and tertiary enrolment ratios. Due to the renewed efforts made by the Asian economies to increase enrolment ratios and allocate resources efficiently in an effort to achieve the MDG of education for all, the present study focuses on Asia. The main difference between our current paper and a number of previous studies in the literature is as follows. We shall argue that the specifications used in the previous studies are appropriate to estimate only the transitional growth effects of education between two steady states. Such growth effects eventually vanish. In contrast we shall use specifications to estimate the permanent growth effects of education. Second, we shall use the extreme bounds analysis (EBA) of Leamer (1985) and its variants to identify and estimate the growth effects of female and male enrolment ratios in the primary and secondary schools and tertiary institutions. Estimates based on EBA reduce model uncertainty and are claimed to be robust. EBA is especially useful when there are several potential explanatory variables and it is necessary to select a few robust explanatory variables.

The structure of this paper is as follows. Section 2 reviews some key papers in the literature on the growth effects of education. Their main features and main findings are summarised in a table. Section 3 discusses some country characteristics of enrolment ratios. Section 4 discusses specification and our alternative approach is discussed in Section 5.

Empirical results are presented and discussed in Section 6 with a brief discussion of EBA. Finally Section 7 concludes.

2. Review of the Literature

Since the work of Mankiw, Romer and Weil (1992), MRW hereafter, and Barro (1991, 1999) there has developed a large literature on the positive association between human capital and economic growth; see Krueger and Lindahl (2001), Gemmel (1996), Kyriacou (1991), Sala-i-Martin (1997), Romer (1990), Hanushek and Kimko (2000), Hanushek and Dongwook (1995), Hanushek and Woessmann (2007) among many others. Human capital is alternatively measured with several variables including: schooling enrolment ratios (MRW, Barro 1991, Levine and Renelt 1992); the average years of schooling (Hanushek and Woessmann 2007, Krueger and Lindhal 2001); adult literacy rate (Durlauf and Johnson 1995, Romer 1990); and education spending (Baladacci *et al*.2008). There are however, studies that find a weak association between education and growth (Bils and Klenow 2000) or no association (Pritchett 2001). We use enrolment ratios because they are associated with the 3rd MDG. Table 1 below briefly summarises the main features and conclusions of a few seminal studies on the relation between education and economic growth using enrolment ratios.

Many studies using enrolment ratios have found a positive relation between primary and secondary education and economic growth. Barro (1991) uses the initial (1960) enrolment ratios as proxy for the initial stock of human capital. He concludes that the higher the level of initial human capital, the faster the growth rate of per capita income in that country. Augmenting the Solow growth model with a variable for human capital as measured by the secondary enrolment ratio, MRW find that the secondary enrolment ratio explains a large proportion of growth variation in GDP per capita. Gemmel (1996) using a measure of human capital derived from school enrolments and labour force participation rates, shows that primary and secondary enrolments have a greater impact on economic growth in the developing economies while tertiary enrolment has a greater effect on economic growth in the developed economies. Employing regression tree methods and categorising countries by their levels of output and literacy, Durlauf and Johnson (1995) argue that economies can achieve multiple equilibria depending on the levels of output and literacy in a country. Investigating the robustness of various variables on economic growth, Levine and Renelt (1992) show support for conditional convergence between the 1960-1989 period when the

Table 1

Summary of the Literature

Author/s	Education Measure	Sample	Estimation Technique	Coefficient Estimate	Conclusions
Barro (1991)	Initial primary and Secondary enrolment ratios	Annual cross sectional data covering 1960-1985 for 98 countries	OLS	Initial Primary enrolment ratio = 0.01 to 0.02 Secondary enrolment ratio = 0.02 to 0.03 Both initial primary and secondary enrolment are statistically significant. (Table 1, pg.410)	The higher the initial level of human capital the faster the growth in per capita income.
Mankiw-Romer-Weil (1992)	Secondary enrolment ratio	Annual cross sectional data covering the 1960-1985.	OLS	Secondary enrolment ratio: Non oil = 0.66 Intermediate = 0.73 OECD = 0.76 Secondary enrolment is statistically significant. (Table 2, pg. 420)	Human capital as proxied by the secondary enrolment ratio explains a large proportion of the variation in income per capita.
Levine and Renelt (1992)	Secondary enrolment ratio	Cross country data for 106 countries from 1969-1989.	Extreme bounds analysis	Secondary enrolment ratio = 3.17 Secondary enrolment ratio is statistically significant (base value Table 1, pg. 947)	Support for conditional convergence when the initial level of human capital included over the 1960-1989 period, but not 1974-1989.
Barro and Sala-i-Martin (1995)	OLS, SUR, IV	Panel data	Secondary and Higher educational attainment. They also divide educational attainment by gender	Male: secondary education = 0.01. to 0.02 Male higher education = 0.03 to 0.06 Male secondary and higher education are positive and statistically significant. Female secondary education = -0.06 to -0.01 Female higher education = -0.04 to -0.08 Individually female secondary and	Male education is positively related with economic growth, female education is negatively related with growth in the SUR estimates.

				higher education are negative and statistically insignificant, but together they are negative and statistically significant. Table 12.3. pg. 425-426)	
Author/s	Education Measure	Sample	Estimation Technique	Coefficient Estimate	Conclusions
Gemmel (1996)	OLS, 3SLS	MRW's (1992) 98 countries covering the 1960-1985 period.	Human capital measure derived from school enrolment rates and labour force participation rates.	Primary human capital = 0.81 for full sample and is statistically significant. Secondary human capital 0.42 for full sample. Tertiary human capital = 1.10 for the OECD group and is statistically significant Table 3, pg. 22)	The change and initial level of primary education are positively related to economic growth. Primary and secondary human capital have a greater effect on growth in the developing economies and tertiary human capital a greater effect on growth in the developed countries.
Durlauf and Johnson (1995)	Secondary enrolment ratio	Cross country data covering 1960-1985	Regression tree methods	The initial secondary enrolment ratio is insignificant for the low output/low literacy (-0.03) and intermediate output/high literacy (-0.11) groups and significant for the intermediate output/low literacy (0.47) and high output/high literacy (0.34) groups. (Table 5 page 375)	Multiple equilibria with the effect of enrolment on economic growth depending on the growth output and literacy level of the country groups.

Author/s	Education Measure	Sample	Estimation Technique	Coefficient Estimate	Conclusions
Temple (1998)	Secondary enrolment ratio	A group of countries covering the 1960-1985 period	Least Trimmed Squares (LTS)	Secondary enrolment ratio is in the range of -0.01 to 0.13 for countries grouped non-oil, intermediate and OECD. (Table 2, page 368)	When excluding outliers and including regional dummy variables the schooling variable is not statistically significant.
Barro (2001)	Male secondary and higher schooling.	Panel data 1965-1995 for 100 countries	3SLS	Male secondary and higher schooling = 0.004 Statistically significant. (Table 2, page 16)	Growth is positively related to secondary and tertiary levels of school attainment of males and only primary level of females.

initial level of human capital is included in the growth equation. Temple (1998) investigating the robustness of MRW's results argues that when outliers are excluded and regional dummy variables are included, the secondary schooling variable loses statistical significance. The relation between schooling and economic growth giving special emphasis to schooling quality is examined in the work of Barro (1999), Hanushek and Kimko (2000), Hanushek and Dongwook (1995), Hanushek and Woessmann (2007). Mincer (1974) shows that years of schooling can be used to estimate the returns to education. See Kruger and Lindahl (2001) for a review of the literature on the relation between education and growth. More recently Fogel (2009), reviews the development of economic growth theory in the context of the rapid growth experienced by China, India and Southeast Asia. He observes that a college educated worker is 3.1 times as productive, and a high school graduate is 1.8 times as productive, as a worker with less than a ninth-grade education.

Our objective is to explore the influence of education on economic growth in selected Asian countries. We contribute to the literature by exploring the effects of education on economic growth at the primary, secondary and tertiary levels and also examine the effects of education on economic growth at a gender disaggregated level. Compared to the enrolment ratios, data with other alternative measures of education have many gaps in our sample of Asian countries. Nevertheless we also include number of years of education and expenditure on education in our EBA.

3. Country Characteristics

Table 2 summarises the enrolment ratios at the primary, secondary and tertiary levels disaggregated by gender for the countries under study. The figures indicate that enrolment ratios, particularly at the primary level, have steadily increased in these countries, with the gap between male and female enrolment rates having narrowed significantly over time.

Table 2

Enrolment Ratios 1970-2008 for the Selected Asian Countries

Countries	1970		1980		1990		2008	
	Female	Male	Female	Male	Female	Male	Female	Male
	Primary Enrolment Ratio							
Bangladesh	33.9	67.5	60.8	81.2	69.2	84.8	97.9	90.8
Bhutan	20.1	37.3	24.6	46.5	46.9	61.3	106.3	106.2
Cambodia	26.0	34.6	-	-	-	-	112	119.7
China	-	-	105.4	121.4	122.1	135.1	115.5	111.2
India	60.4	93.0	67.9	96.5	80.6	104.9	111.8	114.6
Indonesia	77.9	88.8	102.4	115.7	116.4	117.0	117.8	121.1
Korea	-	-	105.5	104.8	106.6	105.3	103.5	105.5
Laos	43.8	73.5	87.2	111.5	89.0	112.1	101.9	119.5
Malaysia	83.4	93.9	92.0	93.2	92.0	93.8	96.4	96.8
Maldives	28.7	37.5	35.2	54.3	108.6	114.4	134.8	141.4
Myanmar	84.0	93.9	-	-	92.1	98.4	116.5	117.2
Nepal	7.5	40.4	40.9	124.5	75.6	104.8	106.2	106.9
Pakistan	23.4	61.5	29.0	58.5	33.6	63.3	76.6	92.6
Philippines	-	-	-	-	108.0	110.3	109.1	110.9
Sri Lanka	86.8	88.6	92.5	92.4	107.2	99.6	108.9	106.0
Thailand	75.4	83.5			91.6	92.8	92.3	94.4
Vietnam	-	-	106.5	112.1	-	-	-	-
	Secondary Enrolment Ratio							
Bangladesh	9.0	22.0	9.0	25.0	14.0	29.3	44.6	42,9
Bhutan	-	-	-	-	-	-	-	-
Cambodia	5.9	13	-	-	-	-	36.2	44.4
China	-	-	43.3	59.1	32.5	44.0	78.1	74.3
India	16	37	21.3	41.2	29.4	45.8	51.1	60.2
Indonesia	12.2	22.6	23.0	33.2	43.7	52.1	74.1	74.7
Korea	-	-	70.6	82.6	90.3	94.7	95.2	98.9
Laos	2.2	6.1	14.2	22.5	19.2	28.1	28.4	40.4
Malaysia	27.9	40.7	45.7	49.7	57.7	54.3	70.5	66.0
Maldives	-	-	-	-	-	-	-	-
Myanmar	16.3	25.3	-	-	19.5	25.8	-	-
Nepal	3.0	14.0	7.7	31.0	18.5	43.3	-	-
Pakistan	6.0	23	8.7	24.3	13.2	29.5	27.6	36.9
Philippines	47.2	49.8			71.9	69.6	86.1	70.0
Sri Lanka	52	49	58.0	53.8	74.2	66.6	87.9	85.6
Thailand	14.6	20.2	-	-	30.6	31.0	77.4	71.3
Vietnam	-	-	-	-	63.9	69.7	-	-
	Tertiary Enrolment Ratio							
Bangladesh	0.4	3.3	0.8	4.7	1.3	6.5	5	8.9
Bhutan	-	-	0.4	1.3	-	-	4.8	8.2
Cambodia	-	-	-	-	-	-	4.9	9.1
China	-	-	0.55	1.6	-	-	23.1	22.2
India	-	-	2.7	7.0	4.1	7.8	11.0	15.7
Indonesia	1.3	4.1	-	-	7.8	11.6	20.4	22.1
Korea	-	-	6.0	19.2	23.4	49.3	79.1	115.3

Laos	-	-	0.2	0.5	0.7	1.5	1.9	3.5
Malaysia	-	-	3.1	5.2	-	-	36.2	28.1
Maldives	-	-	-	-	-	-	-	-
Myanmar	-	-	-	-	4.8	3.9	12.4	9.1
Nepal	-	-	-	-	2.8	8.4	-	-
Pakistan	-	-	1.2	3.1	2.1	4.0	4.8	5.8
Philippines	-	-	25.9	22.3	30.4	20.6	31.8	21.7
Sri Lanka	0.8	1.4	-	-	2.1	4.4	-	-
Thailand	-	-	-	-	20.9	17.9	49.2	40.3
Vietnam	-	-	-	-	8.1	11.1	-	-

Source: World Development Indicators 2010.

Table 2 shows that there have been significant increases in the primary enrolment ratio in Bangladesh, Bhutan, Cambodia, India, Laos, the Maldives and Nepal, particularly that of female enrolment. The primary enrolment ratio has increased at a much slower pace in Pakistan, while China, Indonesia, Korea, Malaysia, Myanmar, Philippines, Sri Lanka, Thailand and Vietnam have relatively high primary enrolment ratios from the 1970s onward. Secondary enrolment is much lower in all economies in the 1970s, however, have increased to over 70% by 2008 in China, Indonesia, Korea, Malaysia (for females), Philippines, Sri Lanka and Thailand. Cambodia, Laos and Pakistan face very low secondary enrolment ratios of below 50% as of 2008. The tertiary enrolment ratio is exceptionally high in Korea compared to the rest of Asia, while China, Indonesia, Malaysia and Thailand have reasonably high tertiary enrolment ratios compared to the other Asian nations. Unfortunately enrolment data are not available for Singapore.

4. Specification

The papers reviewed in the previous section use similar specifications to estimate the growth effects of selected explanatory variables such as education with pure cross section or panel data methods. In the cross section studies the dependent variable is the sample average growth rate of per capita income and in the panel studies it is usually a five year average or annual growth rate. The specification of this growth equation can be expressed as follows.

$$\Delta \ln y_{it} = \alpha + (1-\lambda)\ln y_{i0} + \beta X_{it} + \pi Z_{it} + \varepsilon_{it} \qquad (1)$$

where $\Delta \ln y =$ an average or annual growth rate of per capita income, $\ln y_{i0} =$ initial per capita income, $X =$ set of enrolment ratios of interest, $Z =$ a set of control variables, and $\varepsilon =$

error term with the classical properties. The i and t subscripts are, respectively, for the cross-section and time series dimensions.

Although many empirical works state that their specifications are based on an endogenous growth model, it can be argued that they are observationally equivalent to the extensions to the exogenous Solow (1956) growth model of MRW, Islam (1995) and Barro (1996).[1] In these works the steady state solution for the *level* of per capita income (y^*) for the Solow model is derived at first and then the following partial adjustment equation is used to explain the actual rate of growth.

$$\Delta \ln y_t = \lambda(y^* - y_t) \qquad (2)$$

In the MRW human capital augmented Solow model y^* depends on the investment ratios of physical capital (s_K) and human capital (s_H). Therefore, it can be assumed that $y^* = \Phi(s_K, s_H)$. Equation (2) is estimated by MRW with a pure cross-section method for the period 1960-1985 with a sample of 98 countries of both developed and developing countries. There are no control variables in the MRW equation and therefore, equations (1) and (2) can be written as:

$$(\ln y_t - \ln y_0) = -\lambda \ln y_0 + \lambda\Phi(s_{Kt},\ s_{Ht}) \qquad (3)$$

where y_0 is income per worker in the initial year, which is 1960 in the MRW sample. Thus the dependent variable is the proportionate change of per worker income over 1960-1985; see Table V in MRW. This equation was used by MRW mainly to estimate the speed of convergence of incomes in the developed and developing countries and not to estimate the permanent growth effects of variables like s_K and s_H because these ratios have only permanent level effects and no permanent growth effects on output. Therefore, it is difficult to accept that the permanent growth effects of variables can be estimated with the specification in (3) or its variants used by Islam (1995) and Barro (1996). Furthermore, following Barro,

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[1] For instance Levine and Renelt (1992, FN. 3) say, incorrectly in our view, that Barro's growth equation is based on endogenous growth models.

subsequent cross country studies added a number of economic, social and political variables, such as education, trade openness, financial development, rule of law, democracy, religion and institutional reforms etc., to the Φ function as potential determinants of the steady state level of income. Justification for these additional variables is generally based on one or another endogenous growth model although it is difficult to identify an endogenous growth model where the growth rate depends on all thee variables. Since the dependent variable is the rate of growth of output, estimates of equations (1) or (3) or similar equations are interpreted as growth equations and the coefficients of the explanatory variables as if they are the permanent or long run growth effects of these variables. However, it is difficult to accept these arguments because the main objective of MRW in estimating (3) was to test the convergence hypothesis and not to estimate the permanent growth effects of variables.[2] The transient growth effects in (3) will vanish when the economy reaches its steady state. Therefore, equation (3) is not appropriate for estimating the permanent growth effects of the variables in X.[3]

Consequently, if equation (1) is used to estimate the growth effects of *X* they will be overestimated because these growth rates will also be affected by the transitory growth rates. This can be seen from the reported somewhat high estimates of the coefficients of enrolment ratios in Table 1. Their transitory growth rates may persist for some time but they are not the same as the long run or permanent growth rates of the X variables.

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[2] The convergence hypothesis is widely tested because its acceptance is seen to validate, indirectly, the neoclassical growth models of Solow (1956), Swan (1956), Cass (1965) and Koopmans (1965) against the endogenous growth models of Romer (1986). Islam (1995) states this more explicitly.

[3] Both pure cross section and panel data studies claim that their objective is to estimate the long run or the permanent growth effects of *X*, given that *Z* is the control variable. If this is the main objective the average growth rates are not good proxies for the unobservable SSGR. Conceptually SSGR is similar to the natural rate of unemployment (NRU) and both are to be derived from the estimates of appropriate dynamic models by imposing the equilibrium or steady state conditions. Proxying SSGR with some average growth rate is similar to proxying the NRU with some average unemployment rate.

5. An Alternative Approach

We shall use the standard exogenous growth model of Solow (1956).[4] For simplicity we shall ignore human capital and the cross-section dimension. With these simplification the Cobb-Douglas production function with constant returns and Harrod neutral technical progress is as follows.

$$Y_t = K_t^{\alpha} \left(A_t L_t\right)^{1-\alpha} \tag{4}$$

where A is the stock of knowledge, Y is income , K is capital and L is employment. The solution for the steady state level of per worker income is:

$$y^* = \left(\frac{s}{d+g+n}\right)^{\frac{\alpha}{1-\alpha}} A \tag{5}$$

where $y = (Y/L)$. The steady state growth rate (*SSGR*), when the parameters in the brackets remain constant, is:

$$\Delta \ln y^* = \Delta \ln A = g \tag{6}$$

In the Solow model although the stock of knowledge (A) is assumed exogenous, in the empirical work it is common to assume that A grows at a constant rate of g, i.e.,

$$A_t = A_0 e^{gt} \tag{7}$$

where A_0 is the stock of knowledge in the initial period. It is reasonable to extend by making the stock of knowledge to depend, besides time, on other variables, M_i, which are found to be

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[4] There is no clear-cut evidence that endogenous growth models can explain observed facts better than the simpler exogenous growth model of Solow (1956); see Jones (1995) and Parente (2001). Barro (1996) and Rogers (2003) also observed that the older neoclassical growth theory still continues to provide inspiration to cross-country studies. Barro (1996, p. 4) noted, “It is surely an irony that one of the lasting contributions of endogenous growth theory is that it stimulated empirical work that demonstrated the explanatory power of the neoclassical growth model.”

growth enhancing by some endogenous models.[5] To extend the Solow model we assume that g in (7) is a function of the M variables, so that:

$$A_t = A_0 e^{(g_0 + g_i M_{it})t} \qquad i = 1.....n \qquad (8)$$

The advantage of this extension is that it is relatively easy to estimate the permanent growth effects of M_i. In (8) *TFP* is: $g = g_0 + \sum g_i M_i \quad i = 1...n,$ where g_0 captures the effects of the neglected but trended variables. Thus, the long run growth rate depends on the levels of the M_i variables, as in the endogenous models. The coefficients $g_i \quad i = 0...n,$ should be significant if the M_i variables have externalities.

What are some important and potentially growth improving variables for inclusion into the M vector? Durlauf, Johnson, and Temple (2005) found that the number of such potential growth improving variables in empirical work is as many as 145. There is no endogenous growth model in which the specification to estimate permanent growth effects use more than one or two growth enhancing and control variables. Additional explanatory variables are often included in empirical work on an heuristic rather than a theoretical basis if they are supposed to have some potential externalities. However, the growth equations estimated in these studies use variants of equation (1), which we argued is not appropriate for estimating the permanent growth effects of variables of interest. Using a similar specification and pure cross section methods, Levine and Renelt (1992) have used the extreme bounds analysis of Leamer (1985) and found that many fiscal and monetary policy variables have no effects or doubtful effects in the cross-country growth regressions. In contrast, using a less stringent criteria, Sala-I-Martin (1997) found that out of 62 explanatory variables used in various empirical studies, 25 variables have robust growth effects of which three are MUST use variables. These are initial income, life expectancy and years of primary schooling and they should be included in all growth regressions.[6] However, it is not clear how many

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[5] This type of extension to the Solow (1956) growth model has been used in several studies by Rao and his co-authors. A few recent studies are Rao and Cooray (forthcoming), Rao and Vadlamannati (2011), Rao (2010a and 2010b) and Rao, Tamazian and Singh (2010) and Rao and Hassan (2011) etc.

[6] Levine and Renelt have also used four MUST use variables which are investment ratio, initial per capita income, secondary school enrolment ratio and the rate of growth of population. For the list of the 22 significant variables in Sala-I-Martin (1997) see Table 1 in his paper.

variables will be robust if the growth equations are estimated with panel data methods. Using panel data methods and the specifications based on equations (4) to (8), Rao and Vadlamannati (2011) have found with *EBA* that ten variables have robust permanent growth effects; see Table 7 in Rao and Vadlamannati (2011).[7] For pragmatic reasons, it seems necessary to follow some methodological norms in growth empirics.[8] In this paper to estimate the growth effects of enrolment ratios and select other control variables we shall use EBA with alternative assumptions. This would help understand the sensitivity of the effects of enrolment ratios to alternative model specifications, which we expect will reduce model uncertainty.

6. Empirical Results

Estimation of cross country growth regressions is often problematic due to the presence of outliers in the data, parameter heterogeneity and model uncertainty. Therefore, Temple (1998 and 2001) and Sturm and de Haan (2005) suggest estimating cross country growth equations with some robust methods such as the Least Mean Squares (LMS), Least Trimmed Squares (LTS) or EBA. LMS and LTS use OLS and are more suitable to identify outliers. Therefore, they can be used to estimate pure cross section growth regressions. Applications with LMS and LTS to estimate time series models or with panel data methods are yet to be developed.

Levine and Renelt (1992) and Sala-I-Martin (1997) have used EBA to estimate pure cross country growth equations but used two different criteria to identify the robust growth enhancing variables. Following some suggestions in Temple (2000), Sturm and de Haan (2005) have combined EBA and LTS to estimate only pure cross section growth equations with *OLS*. To the best of our knowledge, panel data routines to use LMS, LTS and a combination of them with EBA are not yet available to the applied researchers. Therefore, in this paper we shall use a panel data based EBA routine, available to us and used by Rao and Vadlamannati (2011), to examine in this paper if enrolment ratios and other proxies for education have any robust and permanent growth effects. This is the only tractable option available to us for using EBA to reduce model uncertainty with panel data methods.

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[7] These are time trend, four components of globalisation, investment ratio, ratio of current government expenditure, rate of inflation, civil disturbances, and quality of institutions.

[8] By methodological norms we mean that there are no right or wrong answers.

The central idea of EBA is that out of a range of possible models it enables to examine how sensitive parameter estimates are to different specifications.[9] As noted by Sala-I-Martin, “The problem faced by empirical growth economists is that growth theories are not explicit enough about what variables belong in the ‘true’ regression.” Therefore, he has used EBA to identify a good number of robust growth determinants. EBA can be briefly explained as follows. The general form of the regression, which is usually estimated in *EBA* is:

$$\lambda = a_j + b_{yj} y + b_{zj} z + b_{xj} x + \varepsilon_j \qquad (9)$$

where y is a vector of fixed variables that always appear in the regressions (e.g., Sala-I-Martin’s three MUST variables), z denotes the variable of interest (e.g., one or all of the six enrolment ratios in our case) and x is a vector of three variables selected from the pool X of additional plausible control variables. In growth equations as many as 140 plausible control variables can be used. However, Levine and Renelt (1992) suggest that a few crucial control variables may be adequate, which in their EBA exercise were eight. Cross section and time subscripts are ignored in equation (9) for convenience. According to Levine and Renelt (1992) this design tries to reduce multi-collinearity problems by restricting the total number of explanatory variables to eight or fewer, choosing a small pool of variables from the X vector and excluding variables that might measure the same phenomenon. This specification design minimizes the risk of underspecified models while also minimizing the computer power needed to estimate the models.

Adapted to our purpose for testing the robustness of the components of enrolment ratios, the only variable we shall include in vector y is the log of per worker capital stock $(\ln(K/L) = \ln k),$ where $Y =$ real GDP and $L =$ employment. Alternative sets of variables can be selected for inclusion in the vectors z and $x.$ First, we shall include all other potential growth affecting variables, which in our case are 13, in the z vector. Therefore, the set of three explanatory variables in $x,$ which change in each regression, are also selected from $z.$ In other words the vectors X and z have the same variables. These variables are a time trend

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[9] Both LMS and LTA are useful to identify outliers in the data and estimate *OLS* regressions without these outliers. Bayesian methods have been also developed as an alternative to EBA to reduce model uncertainty. However, application of the Bayesian methods need balanced panel data. In contrast EBA can be applied to unbalanced data.

(T), investment ratio ($IRAT$), a measure of trade openness ($TRAT$), a proxy for the development of financial sector ($M2RAT$), the ratio of government current expenditure ($GRAT$), ratio of migrant workers' remittances to home country ($REMRAT$), foreign direct investment ($FDIRAT$) and six enrolment ratios viz., female enrolment ratio in primary schools ($FPRI$), female enrolment ratio in secondary schools ($FSEC$), female enrolment ratio in tertiary institutions ($FTER$), male enrolment ratio in primary schools ($MPRI$), male enrolment ratio in secondary schools ($MSEC$) and male enrolment ratio in tertiary institutions ($MTER$).

We perform three EBA exercises with alternative assumptions. Firstly, we include only the log of per worker capital stock in the y vector since we are estimating a production function. We include all other variables in the z and x vectors to get an idea of which variables have robust growth effects. Next, we repeat the first exercise by including time trend as an additional MUST variable in the y vector. Time trend is likely to capture the growth effects of trended and excluded variables from the production function. This would help to know if the enrolment ratios have any independent permanent growth effects. The final EBA exercise is to check if total secondary school enrolment ratio or male and female enrolment ratios are robust enough to capture the growth effects of education. The specification of our extended production function with these variables is as follows:

$$\begin{aligned}\ln y_{it} &= \ln A_0 + \alpha \ln k_{it} + g_1 T + (g_2 IRAT_{it} + g_3 TRAT_{it} + g_4 M2RAT_{it} \\ &+ g_5 GRAT_{it} + g_6 REMRAT_{it} + g_7 FDIRAT_{it} + g_8 FPRI_{it} + g_9 FSEC_{it} \\ &+ g_{10} FTER_{it} + g_{11} MPRI_{it} + g_{12} MSEC_{it} + g_{13} MTER_{it})T + \varepsilon_{it}\end{aligned} \quad (10)$$

where $A_0 =$ initial stock of knowledge and $\varepsilon_{it} \sim N(0, \delta^2)$. The justification for including these seven variables as growth improving control variables, viz., T to $FDIRAT$ (in addition to $\ln k$) is well known but a brief justification is as follows. There is significant empirical evidence from cross country growth equations that the investment ratio, trade openness and financial development have positive growth effects and the ratio of government current expenditure has a small negative growth effect. The growth effects of remittances and foreign direct investment are somewhat uncertain and controversial. A time trend is included separately to capture the growth effects of other neglected but usually trended explanatory variables. The six gender based enrolment ratios are included because they are the variables of interest to us. So far in many previous studies the secondary school enrolment ratio has been used as a proxy to measure the growth effects of education or human capital. Therefore, our findings with six gender-based enrolment ratios will be of considerable use to policy makers. In particular we will also know how robust is the secondary school enrolment ratio as a proxy to measure the growth effects of education.

For each model *j* one estimate of b_{zj} and the corresponding standard deviation σ_{zj} are made. The lower extreme bound for this parameter is defined as the lowest value of $b_{zj} - 2\sigma_{zj}$ and the upper extreme bound is the largest value of $b_{zj} + 2\sigma_{zj}$. If the lower extreme bound is negative and the upper extreme bound is positive, according to Leamer and Levine and Renelt, the effect of the variable is fragile. This criterion of Leamer (1983, 1985) was criticized by McAleer et.al., (1985) and Sala I Martin (1996, 1997) as too stringent. Sala I Martin proposed an alternative criterion based on the cumulative distribution function (*CDF*) of the estimated coefficients. He selected 0.95 as the critical value for the CDF, which implies that 95% of all the estimates of a coefficient are within the plus and minus two standard errors of this coefficient. If the CDF for a coefficient is equal to or more than 0.95, then the effects of the variable is considered to be robust, whereas in Leamer's criterion if the estimated coefficient changes sign once, it is considered to be a fragile variable.

The results of the EBA exercises of equation (10) are in Tables 3 to 5. Data for 18 Asian countries from 1970 to 2009 is divided into eight panels of five years. Countries included range from the newly industrialised ones such as Korea to the rapidly growing countries such as China and India. In addition, we include the relatively neglected small countries including Bhutan and Nepal. The countries in our sample are listed in the appendix.

Our results in Table 3 are different to those of Levine and Renelt (1992) and Sala-I-Martin (1997). In both studies there have been significant differences between the selected robust variables. However, in our EBA the Levine and Renelt criteria in column (3) and the Sala-I-Martin criteria in column (4) select the same set of robust variables. Furthermore, the t-ratios in column (2) can also be used for this purpose. The variables that are significant at the 95% level are also robust according to the criteria in columns (3) and (4). The selected robust variables are capital per worker $(\ln k)$, investment ($IRAT$), trade ($TRAT$), financial development $(M2RAT)$, foreign direct investment ($FDIRAT$), government expenditure $(GRAT)$ and primary and secondary enrolment ratios for both female and males ($FPRI$, $MPRI$, $FSEC$ and $MSEC$). The fragile variables are time trend (T), remittances $(REMRAT)$ and tertiary enrolment ratios for both females and males $(FTER$ and $MTER)$. Thus out of 14 variables 10 are robust and 4 are fragile.

How large are the growth effects of these ten robust variables and in particular the school enrolment ratios? For this purpose it seems reasonable to use the average estimated value of the correctly signed coefficients in column (1). But prior to this it should be noted that the estimated coefficient of profit share (α) at about 0.4 is a reasonable estimate and close to its stylised value of one third in the growth accounting exercises. Among the non-educational control variables foreign direct investment has the largest permanent growth effects. A ten point increase in this variable adds almost 1% to the growth rate. Furthermore, its growth effects are almost three times larger than domestic investment. Trade openness and financial development have similar growth effects. A ten point increase in both variables adds 0.2% to the growth rate. The growth effects of remittances although positive are insignificant. A positive and significant coefficient for government expenditure is contrary to expectation. However, it is likely that its effects are positive because some of the current government expenditure consists of payment of salaries to teachers in government schools, health workers and staff employed in various development schemes.

Table 3 Extreme Bounds Analysis-1 $\ln y_{it} = \ln A_0 + \alpha \ln k_{it} + g_1 T + (g_2 IRAT_{it} + g_3 TRAT_{it} + g_4 M2RAT_{it}$ $+ g_5 GRAT_{it} + g_6 REMRAT_{it} + g_7 FDIRAT_{it} + g_8 FPRI_{it} + g_9 FSEC_{it}$ $+ g_{10} FTER_{it} + g_{11} MPRI_{it} + g_{12} MSEC_{it} + g_{13} MTER_{it})T + \varepsilon_{it}$						
	(1)	(2)	(3)	(4)	(5)	(6)
Variables	Average Coefficient	Average t-ratio	LR Score	CDF	Lower Bound	Upper Bound
T	0.0015	1.00	0	0.84	-0.0015	0.0045
$\ln k$	0.3967	11.53	1	1	0	0.4656
$IRAT \times T$	0.0312	3.30	1	0.99	0	0.0501
$TRAT \times T$	0.0111	4.48	1	1	0	0.0161
$M2RAT \times T$	0.0103	3.11	1	0.99	0	0.0170
$GRAT \times T$	0.0593	2.61	1	1	0	0.1047
$REMRAT \times T$	0.0283	1.41	0	0.92	-0.0119	0.0685
$FDIRAT \times T$	0.0869	2.37	1	0.99	0	0.1601
$FPRI \times T$	0.0064	2.68	1	1	0	0.0112
$FSEC \times T$	0.0107	2.86	1	1	0	0.0181
$FTER \times T$	0.0033	0.41	0	0.66	-0.0128	0.0195
$MPRI \times T$	0.0064	2.79	1	1	0	0.0110
$MSEC \times T$	0.0110	2.80	1	1	0	0.0184
$MTER \times T$	$2.1E^{-5}$	0.00	0	0.50	-0.0134	0.0134

Notes: Only $\ln k$ is included in the y vector. All the 14 explanatory variables (including capital per worker) are included in the z and x vectors; see equation (9). This gives an idea on how robust $\ln k$ as an explanatory variable is.

The coefficients of the female and male secondary enrolment ratios are similar at about 0.01, implying that a 10 point increase in both secondary enrolment ratios will permanently increase the growth rate by 0.2%. Likewise the coefficients of female and male primary enrolment ratios are similar but have smaller growth effects compared to the secondary school enrolment ratios. The growth effects of the secondary enrolment ratios are about 1.6 times larger than primary school enrolment ratios. This may be due to the fact that the former's effects are partly captured by the latter because those in the secondary schools have already completed primary education. Furthermore, it is also likely that a large number of primary schools are located in the rural and remote areas and inadequately staffed and resourced. It is surprising that the coefficients of the two tertiary enrolments are insignificant which makes them as fragile variables. This is of some concern because tertiary institutions are likely to be located in the urban areas and generally well staffed and funded.

The second EBA exercise shows how sensitive the results in Table-3 are to a change in the variables in the vector y, which consists of variables that should always be included in all regressions. Although time trend is found to be not a robust variable in Table-3, TFP is generally assumed to follow a deterministic trend pattern. EBA results with both capital and trend in the y vector are shown in Table-4.

Table 4

Extreme Bounds Analysis-2

$$\ln y_{it} = \ln A_0 + \alpha \ln k_{it} + g_1 T + (g_2 IRAT_{it} + g_3 TRAT_{it} + g_4 M2RAT_{it}$$
$$+ g_5 GRAT_{it} + g_6 REMRAT_{it} + g_7 FDIRAT_{it} + g_8 FPRI_{it} + g_9 FSEC_{it}$$
$$+ g_{10} FTER_{it} + g_{11} MPRI_{it} + g_{12} MSEC_{it} + g_{13} MTER_{it})T + \varepsilon_{it}$$

	(1)	(2)	(3)	(4)	(5)	(6)
Variables	Average Coefficient	Average t-ratio	LR Score	CDF	Lower Bound	Upper Bound
$\ln k$	0.3863	11.14	1	1	0	0.4557
$IRAT \times T$	0.0354	3.19	1	0.9993	0	0.0503
$TRAT \times T$	0.0118	4.51	1	0.9999	0	0.0170
$M2RAT \times T$	0.0108	3.04	1	0.9988	0	0.0179
$GRAT \times T$	0.0595	2.54	1	0.9938	0	0.1063
$REMRAT \times T$	0.0310	1.48	0	0.9190	-0.0108	0.0727
$FDIRAT \times T$	0.0848	2.28	1	0.9877	0	0.1594
$FPRI \times T$	0.0065	2.59	1	0.9965	0	0.0182
$FSEC \times T$	0.0106	2.76	1	0.9974	0	0.0181
$FTER \times T$	0.0048	0.61	0	0.7279	-0.0110	0.0207
$MPRI \times T$	0.0065	2.69	1	0.9959	0	0.0113
$MSEC \times T$	0.0106	2.69	1	0.9958	0	0.0185
$MTER \times T$	0.0014	0.23	0	0.5857	-0.0118	0.0147

Notes: Only $\ln k$ and T are included in the y vector. All other explanatory variables (including capital per worker) are included in the z and x vectors; see equation (9). This gives an idea of how robust $\ln k$ as an explanatory variable is.

It can be seen that these results are similar to Table-3 with very small changes to the estimates of the average coefficients. The three criteria in columns (2), (3) and (4) indicate that the same ten variables are robust. Finally, we show in Table-5 whether the frequently used proxy, secondary school enrolment ratio, to measure the growth effects of education is a robust proxy. To conserve space we show the EBA results for this variable only and there are no significant changes in the estimated average coefficients of other variables. Firstly, EBA result for the total (male and female) secondary school enrolment ratio is shown in row (1) and then in rows (2) and (3) results with the female and male secondary school enrolment ratios are shown. Total enrolment ratio is now fragile and its average coefficient is negative and highly insignificant. On the other hand the female and male secondary enrolment ratios are robust and there is no change in their estimated average coefficients. While it is difficult to say that disaggregated enrolment ratios are better proxies for education than total secondary school enrolment ratio, it can be said that if total secondary school enrolment ratio is found to be fragile in some samples, it is worth trying with disaggregated enrolment ratios.

Table 5
Extreme Bounds Analysis-3

	(1)	(2)	(3)	(4)	(5)	(6)
Variables	Average Coefficient	Average t-ratio	LR Score	CDF	Lower Bound	Upper Bound
$SEC \times T$	-0.0008	-0.11	0	0.55	-0.0154	0.0138
$FSEC \times T$	0.0105	2.76	1	1	0	0.0182
$MSEC \times T$	0.0106	2.69	1	1	0	0.0185

Notes: Only $\ln k$ and T are included in the y vector.

7 . Summary and Conclusions

This study employed the Extreme Bounds Analysis to investigate the robust but permanent growth effects of education disaggregated at the primary, secondary and tertiary levels by gender for a panel of Asian countries. Both the stringent criteria of Levine and Renelt (1992) and Sala-I-Martin's (1997) criteria based on the cumulative distribution of the estimates of the coefficients indicated that female and male primary and secondary school enrolment ratios have robust but small permanent growth effects. These effects are similar in magnitude for both sexes but the growth effects of secondary school enrolment ratios are about 1.5 times more than primary school enrolment ratios. The growth effects of tertiary enrolment ratios are insignificant for both sexes.

In addition to the enrolment ratios, six other variables, used as control variables, are also found to have robust and permanent growth effects. Of these control variables foreign direct investment has the largest growth effect and this is more than twice of the growth effect of domestic investment. Trade openness and development of the financial sector have similar growth effects. Government expenditure, contrary to expectation, has strong positive growth effect and this may be due to public expenditure on education, health and development programmes. Workers' remittances, although found to have fragile growth effects according to the Levine and Renelt (1992) criteria, has a CDF of 0.93 and can be said to have permanent growth effects in some countries if not in all countries.

We hope that our paper will encourage additional empirical work on the permanent growth effects of education and other variables. In particular it would be interesting to disaggregate current government expenditure into various components and estimate their growth effects. However, our conclusions should be interpreted carefully because of some limitations. Our panel data are not balanced because data for some years are not available for all the countries on crucial variables such as GDP, employment, investment and for some enrolment ratios. Therefore, our findings need further analysis by other investigators employing a larger sample of countries.

Data Appendix

Variable	Source
Per capita income(constant 2000 US$)	World Development Indicators 2010
Investment to GDP (IRAT)	World Development Indicators 2010
Trade to GDP (TRAT)	World Development Indicators 2010
M2 to GDP (M2RAT)	World Development Indicators 2010
Government final consumption expenditure to GDP (GRAT)	World Development Indicators 2010
Remittances to GDP (REMRAT)	World Development Indicators 2010
Foreign Direct Investment to GDP (FDIRAT)	World Development Indicators 2010
School enrolment primary female, total % gross (FPRI)	World Development Indicators 2010
School enrolment primary male, total % gross (MPRI)	World Development Indicators 2010
School enrolment secondary female, total % gross (FSEC)	World Development Indicators 2010
School enrolment secondary male, total % gross (MSEC)	World Development Indicators 2010
School enrolment tertiary female, total % gross (FTER)	World Development Indicators 2010
School enrolment tertiary male, total % gross (MTER)	World Development Indicators 2010

Countries used in the study: Bangladesh, Bhutan, Cambodia, China, India, Indonesia, Korea, Lao, Malaysia, Maldives, Myanmar, Nepal, Pakistan, Philippines, Singapore, Sri Lanka, Thailand, Vietnam.

Note: For Bhutan and Myanmar, data for the capital stock were not available and for Lao and Vietnam data were available only for part of the period. For the Maldives and Myanmar enrolment ratios are not available for the full period and for Singapore enrolment ratios were not available.

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